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The Response of Marine Transitional Systems to Human Impact: Problems and Perspectives for Restoration

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Recent improvements of water quality and biological indicators in Hillsborough Bay, a highly impacted subdivision of Tampa Bay, Florida, USA

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ABSTRACT

Hillsborough Bay, the eastern uppermost section of the Tampa Bay system, is surrounded by a large metropolitan complex, supports extensive industrial activity, and serves as a major shipping port of fertilizer products. The Bay was determined to be highly eutrophic during the late 1960s. The City of Tampa's primary sewage treatment plant and runoff from fertilizer industry activities were considered as the major sources of excessive nutrient loading. Loadings from both these sources have been reduced during the last 10 years, which has probably been the leading cause of improved water quality parameters such as water clarity, dissolved oxygen, and chlorophyll. The improvements recorded in these parameters may, in part, be related to large biomass reductions of a planktonic blue-green alga, which used to dominate the fall and early winter phytoplankton population. Coincidental with improved water quality, seagrass and an attached macro-alga have vegetated shallow areas around the bay, which had been barren of attached vegetation for several decades.

INTRODUCTION

Tampa Bay is a shallow, sub-tropical, estuary located on the Gulf of Mexico coast of Central Florida (Fig. 1). It is one of the largest estuaries in the southeastern United States with an open water surface area of 1030 km^2 and with a watershed area of 5700 km^2. Population growth of the Tampa Bay region is one of the greatest in the United States, and approximately 1.7 million people now live within 80 km of the bay (TBRPC, 1989).

Hillsborough Bay is the eastern uppermost section of the Tampa Bay system and its open water area is 105 km^2. Three of Tampa Bay's five major rivers empty into Hillsborough Bay and the bay receives 63% of

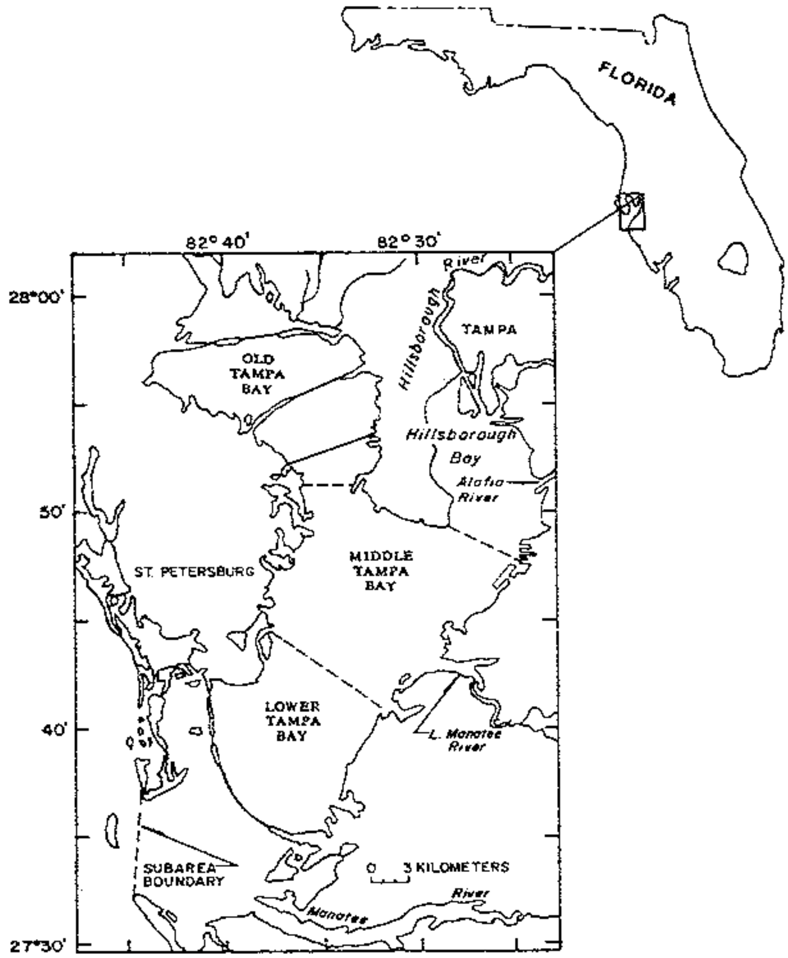

Fig. 1. Tampa Bay, Florida, USA. Map modified from Goetz and Goodwin (1980).

the total surface fresh water flow to Tampa Bay (Goodwin, 1987). The City of Tampa borders Hillsborough Bay to the north and the west. Agricultural lands and extensive phosphate mining areas are located within the drainage area to the east. Also on its eastern shores are several large fertilizer industrial facilities, such as processing plants, storage facilities and ship-loading terminals. The bay serves as a major shipping port of fertilizer products. In 1988 some 20 million tons of fertilizer products were shipped from Hillsborough Bay (Tampa Port Authority, unpublished data), which comprises approximately 80% of the United States production of phosphate fertilizer and 50% of the production of nitrogen containing fertilizer (Bureau of the Census, 1988).

In 1976 the City of Tampa initiated a comprehensive study of phytoplankton productivity and standing crop to evaluate anticipated future abatement of wastewater pollution in Hillsborough Bay. As the study has progressed other important indicators of water quality have been included, such as submerged vegetation monitoring and test plantings of seagrasses. The extensive Tampa Bay water quality data base accumulated by the Environmental Protection Commission of Hillsborough County (HCEPC) as well as Tampa Bay seagrass research conducted by the City of Tampa and Lewis Environmental Services, Inc. will also be used in the discussion of recent environmental improvements in Hillsborough Bay.

PAST WATER QUALITY CONDITIONS

Almost 40 years ago Tampa Bay was described as grossly polluted due to poorly treated municipal wastewater discharges and industrial wastes from phosphate mines, citrus canneries and other industrial sources (Galtsoff, 1954). During the early 1960s, citizens living close to Hillsborough Bay were complaining to the authorities about noxious odors emitting from the bay. Obvious signs of the deteriorated water quality included: high turbidity, high fecal coliform counts, anoxia of bottom waters and large amounts of drift macroalgae in the shallows. Also, most of the submerged seagrasses in Hillsborough Bay were lost by the 1960s, however, not all the loss can be attributed to poor water quality. Extensive dredging and dredge-and-fill activities caused direct losses of habitat and excessive turbidity to surrounding areas (Lewis, 1977; Lewis and Estevez, 1989).

In 1967 and 1968 a comprehensive study of Hillsborough Bay water quality problems was conducted by a federal agency in cooperation with local agencies (FWPCA, 1969). This study confirmed earlier observations of highly deteriorated conditions in Hillsborough Bay. Further, it implicated the Hooker's Point Wastewater Treatment Plant, operated by the City of Tampa, as a major point source polluter based on its release of primary treated wastewater to the bay. It was estimated that discharges from this plant supplied more than 40% of the Kjeldahl nitrogen from point and non-point sources. Other major pollution sources, which supplied almost 50% of the Kjeldahl nitrogen to the bay, were fertilizer processing plants and the Alafia River. It should be noted that the Alafia River drainage area encompasses many phosphate mines and other fertilizer facilities. Excessive waste discharges, followed by algal blooms, fish kills, noxious odors and loss of seagrass meadows, are characteristic of coastal eutrophication as documented in Denmark (Borum, 1983), Australia (Cambridge and McComb, 1984; Cambridge et al., 1986) and France (Meinesz and Laurent, 1978).

CITY OF TAMPA WASTEWATER DISCHARGES

A 1972 State of Florida law required all domestic wastewater dischargers to tidal waters of west-central Florida to provide advanced wastewater treatment (AWT). AWT was defined as 5 mg l^{-1} BOD_5, 5 mg l^{-1} total suspended solids, 3 mg l^{-1} total nitrogen and 1 mg l^{-1} total phosphorus. Directed by this law, the City of Tampa upgraded its Hooker's Point facility from primary to AWT with a 230 x 10^6 liters per day capacity in 1979 (Garrity et al., 1985). This treatment plant is now one of the ten largest in the southeastern United States. A variance for the AWT phosphorus removal requirement has been obtained, because phytoplankton bioassay experiments indicate nitrogen as the most limiting nutrient for algal growth in Hillsborough Bay (City of Tampa, 1983; FDER, 1983).

Total nitrogen loading to Hillsborough Bay from the Hooker's Point facility was reduced an order of magnitude or more when the plant converted from primary to advanced treatment and the ammonia fraction of the total nitrogen discharged was virtually eliminated (Fig. 2).

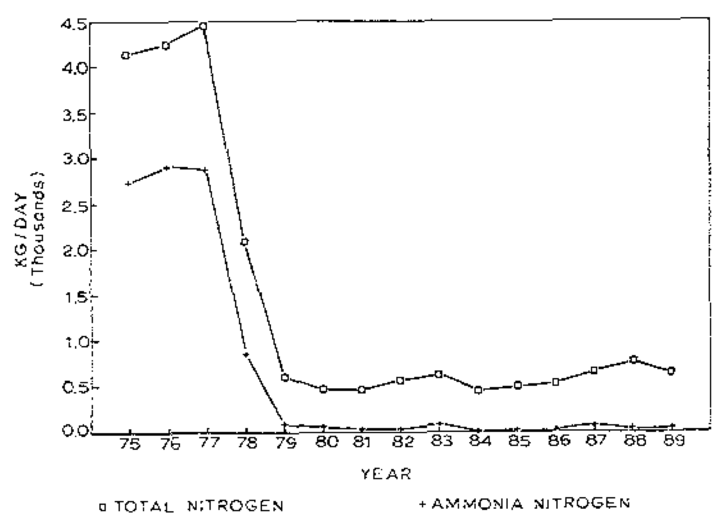

Fig. 2. Loading of total nitrogen and ammonia–nitrogen from the Hooker's Point Wastewater Treatment Plant. See Appendix for data source.

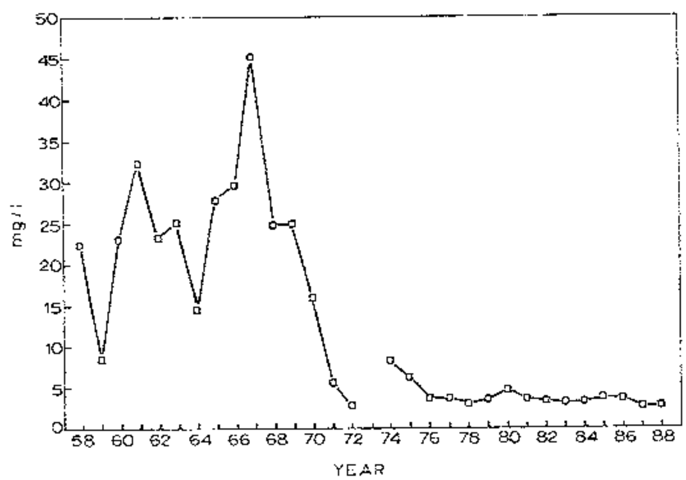

Fig. 3. Phosphorus concentrations in the Alafia River. 1954–72 Data from Reichenbaugh et al. (1973). See the Appendix for data source.

FERTILIZER INDUSTRY AND ALAFIA RIVER IMPACTS

During the late 1800s, rich phosphate deposits were discovered east of Hillsborough Bay and in 1908 the first large vessels were used for transport of phosphate rock from the Tampa Bay area (Tiffany and Wilkinson, 1989). Prior to the 1960s, fertilizer production and export consisted mostly of phosphate rock, however, later the production and export of processed nitrogen containing fertilizer has become increasingly important. In 1989 some 8.5 million tons of diammonium phosphate and monoammonium phosphate were shipped from the Port of Tampa in Hillsborough Bay (Tampa Port Authority, unpublished data).

During the 1967–68 survey of Hillsborough Bay, the FWPCA (1969) found that fertilizer processing plants and the Alafia River together contributed 94% of the total phosphorus and almost 50% of the total Kjeldahl nitrogen entering the bay from point and non-point sources. Recent increased regulation of the fertilizer industry has helped to reduce its impact on the bay (Estevez and Upchurch, 1985), which is illustrated by Alafia River phosphate concentrations over time (Fig. 3) and nitrogen loading from Alafia River and Delaney Creek (Fig. 4). Delaney Creek is a small creek entering the northeastern Hillsborough Bay (East Bay), which has a large nitrogen fertilizer plant located 3 km upstream. Although impacts may have been reduced from upstream sources, large losses of nitrogen containing fertilizer still occur from fertilizer industry facilities such as: processing plants, storage facilities

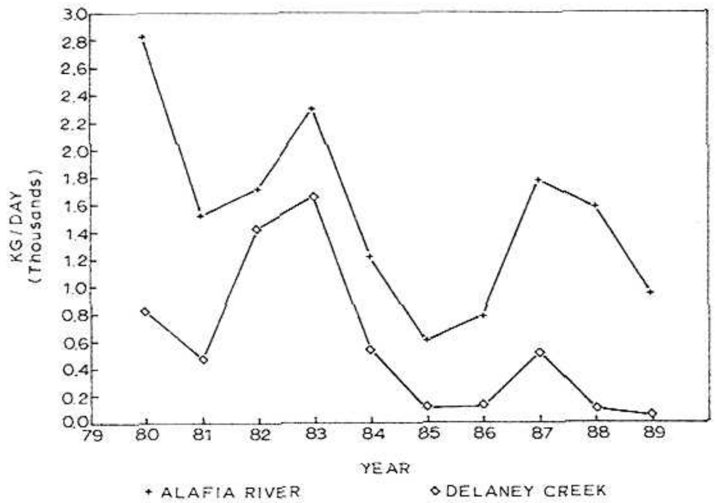

Fig. 4. Total nitrogen loading to Hillsborough Bay from Alafia River and Delaney Creek. See the Appendix for data sources.

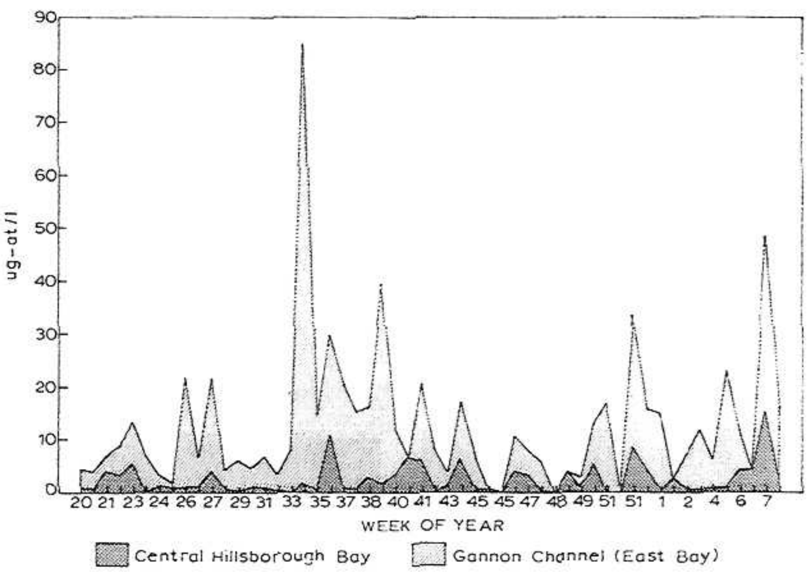

Fig. 5. Ambient ammonia–nitrogen concentrations in East Bay (Gannon Channel) and the central Hillsborough Bay, 1989 and 1990. City of Tampa, unpublished data.

and ship-loading terminals located near or next to Hillsborough Bay. Recent communications with industry personnel and observations of facilities operation, as well as field measurements in the port area of Hillsborough Bay (Fig. 5), indicate that losses from these facilities now appear to be a dominant source of nitrogen to Hillsborough Bay. Furthermore, the amount of nitrogen containing fertilizer handled at these facilities is increasing rapidly (Fig. 6).

NITROGEN LOADING AND PHYTOPLANKTON DEMAND

The large reductions in phosphorus loading from the Alafia River, which occurred in the late 1960s and early 1970s, are reflected in sharply reduced ambient phosphorus concentrations in Hillsborough Bay and the other major sections of Tampa Bay (Goetz and Goodwin, 1980; Boler, 1988; HCEPC, unpublished data). However, the recent substantial reductions in nitrogen loading to Hillsborough Bay primarily from the Hooker's Point Wastewater Treatment Plant, and also from Alafia River and Delaney Creek, are not as clearly mirrored in the ambient nitrogen concentrations of the bay (Fig. 7). However, excluding the peak in 1987, a trend towards lower ambient nitrogen concentrations is suggested since the mid 1980s. The high concentrations found in Tampa Bay in 1987 are unexplained at this time. However, both the HCEPC, and the U.S. Geological Survey record for the Alafia River indicate unusually high concentrations of organic nitrogen in early 1987 (Boler, 1988; U.S. Geological Survey, 1988).

Nevertheless, the importance of the Hooker's Point Wastewater Treatment Plant, Alafia River, Delaney Creek and other point and non-point nitrogen sources can be theoretically assessed relative to the nitrogen

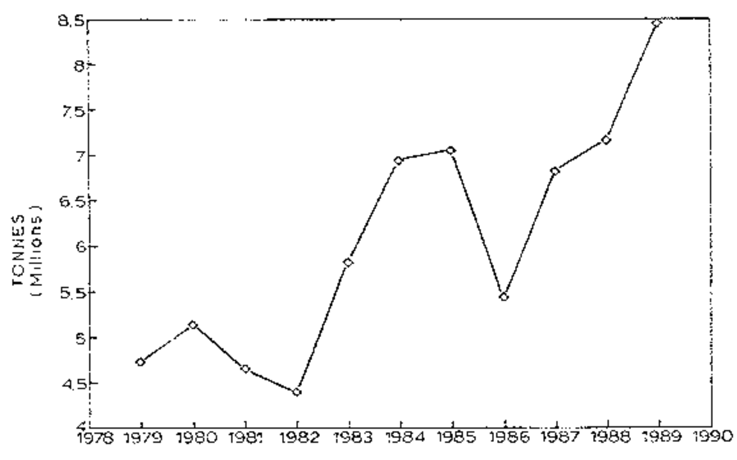

Fig. 6. Outbound ammonium phosphate fertilizer (short tonnes) from the Port of Tampa, Hillsborough Bay. Tampa Port Authority, unpublished data.

demand of the water column primary production. Nitrogen released from internal recycling processes in the bay, such as sediment releases and water column regeneration, are not considered at this time. These internal sources are ultimately a function of the loadings entering Hillsborough Bay (Johansson and Squires, 1989). Phytoplankton production was 530 g C m^{-2} $year^{-1}$ during the period when Hooker's Point changed its treatment from primary to AWT and 460 g C m^{-2} $year^{-1}$ for the period 1984 through 1989. The nitrogen demand is estimated by assuming that phytoplankton production accounts for nearly all of primary production and that phytoplankton assimilate nitrogen in proportion to the Redfield C:N ratio of 106:16. According to these calculations the annual requirement of nitrogen by the Hillsborough Bay phytoplankton was 9400 tons $year^{-1}$ for the pre-1984 period, and 8200 tons $year^{-1}$ for the 1984 through 1989 period (Table 1).

Primary treated discharges from the Hooker's Point facility supplied an estimated 15% of the phytoplankton nitrogen demand. Advanced wastewater treatment greatly reduced the amount of nitrogen discharged and the plant now only supplies a calculated 2.6%. The Alafia River and Delaney Creek have had smaller reductions. These two sources combined now appear to supply 7.5% of the phytoplankton nitrogen demand. Estimated loadings from the fertilizer industry facilities located near or next to the bay now appear to be a major source of nitrogen for the Hillsborough Bay phytoplankton.

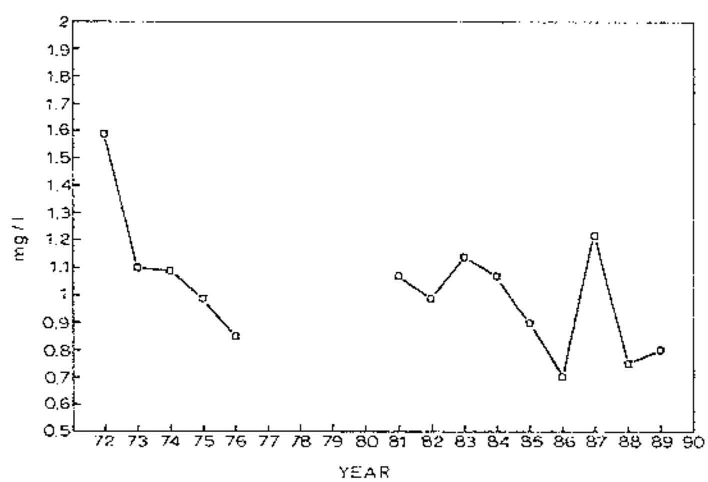

Fig. 7. Total Kjeldhal nitrogen concentrations in Hillsborough Bay. 1972–74 Data from Goetz and Goodwin (1980). 1981–89 Data from Boler (1988) and HCEPC, unpublished data.

TABLE 1

Calculated loadings from major nitrogen sources to Hillsborough Bay during two time periods and the percent of nitrogen each source can supply to the annual phytoplankton demand. See the Appendix for loadings calculations

	Pre 1984		1984–1989	
	Tons year^{-1}	%	Tons year^{-1}	%
Phytoplankton demand	9400		8200	
Alafia River and Delaney Creek	1350	14	610	7.5
Hooker's Point	1370	15	210	2.6
Fertilizer industry	940	10	1330	16
Other rivers and wetfall	780	8.3	890	11
Total	4440		3040	

PHYTOPLANKTON BIOMASS AND TAXONOMIC COMPOSITION

Nitrogen loading to Hillsborough Bay has apparently been reduced by approximately 30% recently and it is reasonable to assume that this reduction has significantly affected phytoplankton biomass. Chlorophyll *a* concentrations, which are estimates of phytoplankton biomass, show a decreasing trend since the mid 1980s (Fig. 8). Although the largest reduction of nitrogen loading to Hillsborough Bay took place between 1979 and 1980, when Hooker's Point converted from primary to AWT, ambient chlorophyll *a* concentrations did not decrease substantially until 4 years later in 1984. Assuming that nitrogen discharges from the Hooker's Point Treatment Plant were the predominant nitrogen loading reduction, then, a time lag of several years appears to exist between reduced nitrogen loading and the response of ambient chlorophyll *a* concentrations in Hillsborough Bay.

The substantial decrease of chlorophyll *a* in Hillsborough Bay correlates with the loss of a planktonic filamentous blue–green alga (*Schizothrix calcicola sensu* Drouet) which prior to 1984 dominated the phytoplankton population from late summer to early winter (Fig. 9). This alga has been present in the bay since 1984, but in much reduced concentrations. Blue–green algae are considered nuisance species and are often indicators of poor water quality (Paerl, 1987).

Fig. 8. Chlorophyll *a* concentrations in Hillsborough Bay. Data from Boler (1988) and HCEPC, unpublished data.

WATER COLUMN LIGHT TRANSPARENCY AND SEAGRASS PERSISTENCE

Phytoplankton biomass is an important factor limiting water column light penetration in phytoplankton dominated estuaries such as Hillsborough Bay. Further the dense concentrations of the blue–green alga found in the bay prior to 1984 may have additionally suppressed light penetration. Kirk (1977) found that blue–green algae reduce light to a greater degree than other phytoplankton types, which may explain improved Secchi depth readings in Hillsborough Bay after the blue–green biomass was reduced (Fig. 10). Sufficient water column light penetration is essential for the survival of submerged seagrasses.

Hillsborough Bay, and Tampa Bay as a whole, have had serious losses of seagrass. Historic records show that the areal coverage of Tampa Bay seagrasses has decreased dramatically during the last one hundred years. In 1982 approximately 5750 ha or 20% of the originally estimated 30 970 ha still remained (Lewis et al., 1985). Virtually all seagrasses in Hillsborough Bay were lost between 1950 and 1984. It should be noted that Hillsborough Bay is the subsection of Tampa Bay which has received the heaviest impact from urbanization and which historically has had the highest levels of chlorophyll *a*; however, declines in total seagrass cover have been recorded in all subsections of Tampa Bay. Modest seagrass recolonization was observed in 1984 in Middle Tampa Bay just south of Hillsborough Bay, and in 1985 in Hillsborough Bay proper. The new seagrass growth followed the substantial decrease in chlorophyll *a*

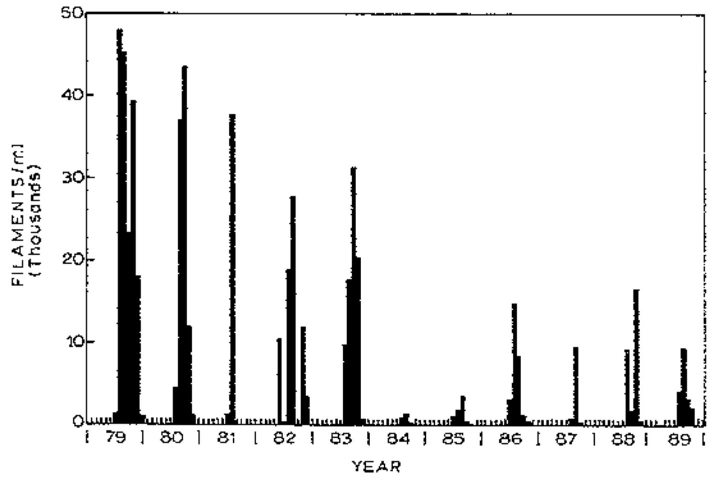

Fig. 9. Monthly concentrations of a filamentous blue-green alga (*Schizothrix calcicola sensu* Drouet) in Hillsborough Bay. Johansson et al. (1985) and City of Tampa, unpublished data.

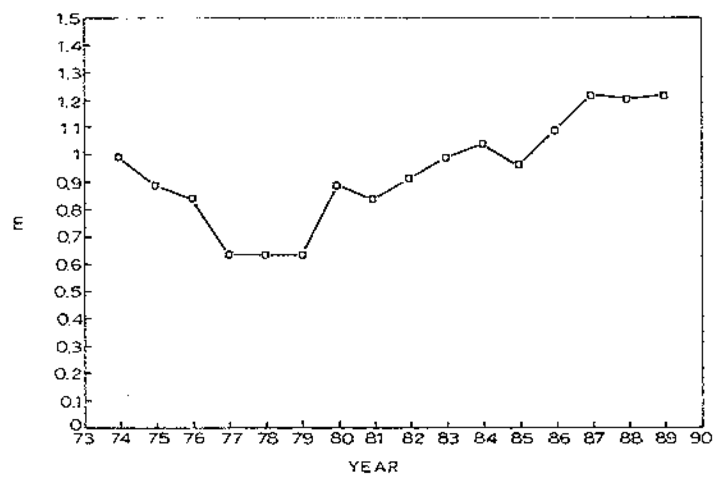

Fig. 10. Secchi depth in Hillsborough Bay. Data from Boler (1988) and HCEPC, unpublished data.

concentration and increase in water column light penetration. An extensive inventory of Hillsborough Bay seagrass coverage in 1986 (City of Tampa, 1988) found 0.2 ha of the shallow sandbars at the perimeter of the bay covered by *Halodule wrightii* (shoalgrass). The inventory also included a small section of Middle Tampa Bay and, based on a comparison with earlier photographs, this area showed 48 ha of new seagrass growth (Fig. 11). By 1989, total Hillsborough Bay coverage, and coverage

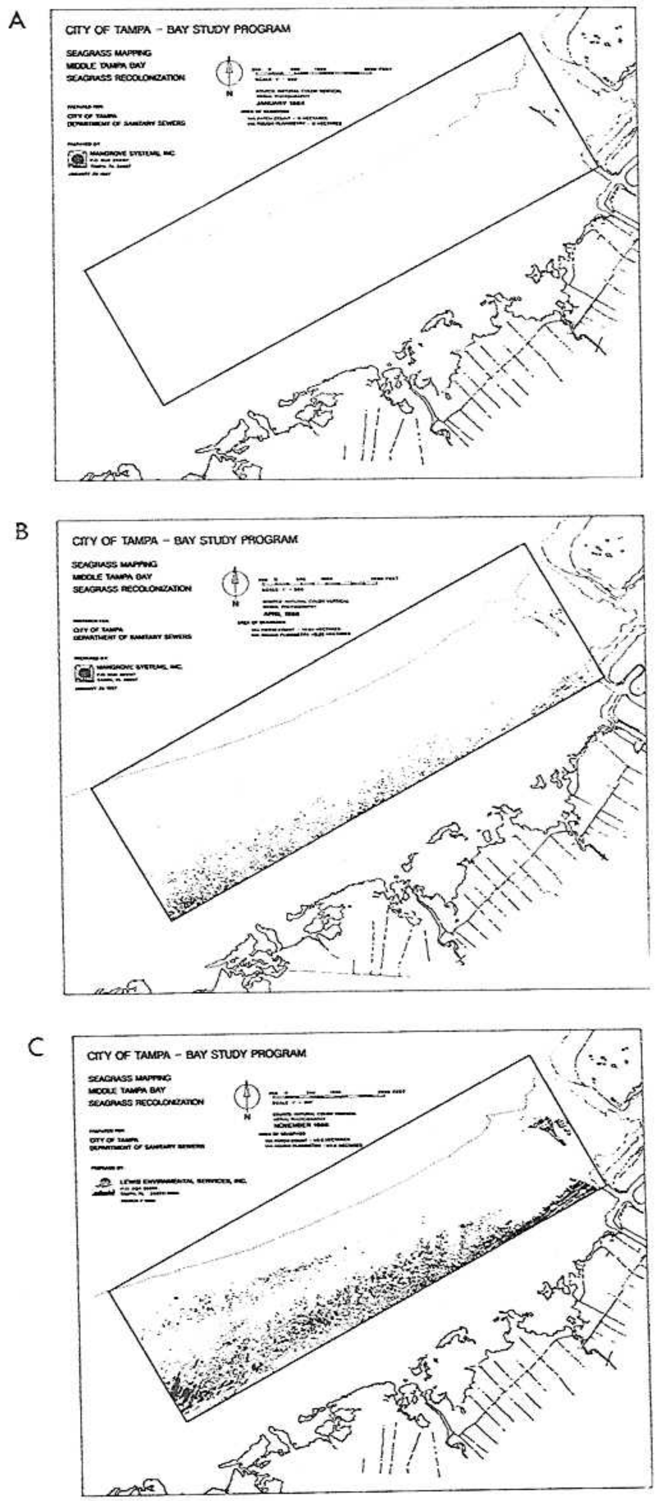

Fig. 11. Natural *Halodule wrightii* cover in Middle Tampa Bay, just south of the entrance to Hillsborough Bay, in (A) 1984, (B), 1986 and (c) 1988. Data from City of Tampa (1988) and Lewis Environmental Services, Inc., unpublished data.

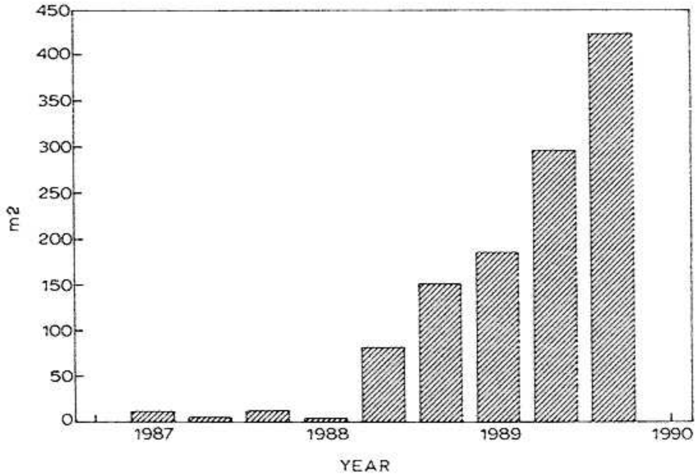

Fig. 12. Area coverage of *Halodule wrightii* test plantings in Hillsborough Bay. Data from City of Tampa (1990).

at the Middle Tampa Bay site, had more than doubled to 0.4 ha and 98 ha, respectively. In addition, deeper portions of the sandbar in Hillsborough Bay had been covered extensively by the rhizophytic macroalga *Caulerpa prolifera*. The habitat created by this alga resembles a seagrass habitat in many ways. Further, test plantings conducted by the City of Tampa of the seagrass *H. wrightii* in 1987 have been successful at several locations in Hillsborough Bay (Fig. 12). These results indicate that many areas of the intertidal and shallow subtidal bottom of Hillsborough Bay may now be available for seagrass colonization either by natural recruitment or artificial introduction through plantings.

CONCLUSION

Hillsborough Bay water quality has recently improved in response to reduced nitrogen loading caused primarily by the conversion of the Hooker's Point Wastewater Facility from primary to advanced treatment. Less nitrogen is now available for phytoplankton growth, and the reduced biomass has apparently allowed for improved water column light penetration. Evidently, seagrasses and the attached macroalga *Caulerpa* have responded to the increased light penetration by colonizing shallow areas. The limited return of seagrass meadows to the shallow bottom is an important sign of improving water quality in Hillsborough Bay.

Although this trend is encouraging, most shallow areas in Hillsborough Bay still lack macrophyte vegetation. Furthermore, relatively high concentrations of chlorophyll *a* still persist, which suggests continued excessive nitrogen loading. A comparison of current major nitrogen sources implies that losses of nitrogen containing fertilizer from fertilizer plants, storage facilities, and ship-loading terminals, located near or next to the bay, now appear to be a dominant source of nitrogen to Hillsborough Bay. Immediate control and management of this nitrogen source appears extremely important to achieve, within the near future, low chlorophyll *a* concentrations and the natural restoration of persistent seagrass meadows in Hillsborough Bay.

APPENDIX

Loading calculations for rivers and creeks have been calculated from U.S. Geological Survey (USGS) flow measurements (U.S. Geological Survey 1980, 1982, 1983, 1985, 1986a, 1986b, 1987, 1988 and unpublished 1989 flows) and from Hillsborough County Environmental Protection Commission (HCEPC) concentration measurements (Boler, 1986, 1988; Cardinale and Boler, 1984; Wilkins, 1980, 1981, 1982 and unpublished 1989 concentrations). Flow measurements are continuous while concentration measurements are limited to once a month collections, at mid depth. Pre-1984 loadings are calculated from 1980 through 1983.

Alafia River flows are measured at Lithia (USGS station 02301500) and concentrations at Bell Shoals Road (HCEPC station 114). An additional 25% of the flow at Lithia has been added to the total river flow in order to account for additional flow entering the river below Lithia.

Delaney Creek flows are measured at Darlington Street (USGS station 02301750) and concentrations at US Highway 41 (HCEPC station 133). Delaney Creek flow information is not available prior to WY 1985, therefore, flows for 1980 through 1984 have been calculated from Bullfrog Creek flows for this period and a regression relationship between Delaney Creek and Bullfrog Creek flows from 1985 through 1989. Nitrogen loading from Delaney Creek for the 1980 through 1983 period is probably underestimated due to at least 8 monthly offscale concentration measurements (99.99 mg l^{-1}).

Other rivers and creeks include Hillsborough River, Tampa By-Pass Canal and Bullfrog Creek.

Hillsborough River flows are measured at the City of Tampa dam (USGS station 02304500) and concentrations at State Road 585 (HCEPC station 105). An additional 30% of the loadings at the dam has been added to the total river loading to account for urban runoff loading entering the river below the dam. This addition is based on findings by Metcalf & Eddy, Inc. (1983a).

Tampa By-Pass Canal flows are measured at structure S-160 (USGS station 02301802) and concentrations at State Road 60 (HCEPC station 110).

Bullfrog Creek flows are measured at State Highway 672-S (USGS station 02300700) and concentrations at Symmes Road (HCEPC station 132).

Hooker's Point Wastewater Treatment Plant flow measurements are continuous and concentration measurements are based on a daily flow proportionate composite sample containing approximately 375 samplings per day. Pre-1984 loadings are calculated from 1975 through 1978.

Fertilizer industry loadings, from sources located near or next to Hillsborough Bay, are calculated by assuming a 0.1% loss of diammonium phosphate and monoammonium phosphate shipped from Hillsborough Bay (Tampa Port Authority, unpublished data). All losses are assumed to be diammonium phosphate. Pre-1984 loadings are calculated from 1979 through 1983.

Wetfall loadings are calculated from rain over the open bay and the nitrogen content of rain is taken from Hartigan and Hanson-Walton (1984). Rainfall is measured at Tampa International Airport by NOAA (1988).

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